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Time-Sharing Manual Control and Memory Search: The Joint Effects of Input and Output Modality Competition, Priorities and Control Order

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This report addresses some of the issues that must be considered as voice recognition and synthesis (VRAS) technology is integrated into complex man-machine system environments. These issues include the input and output channels demanded by competing activities, task difficulty or workload, the allocation of attention and the nature of the task that--spatial or verbal--will be interfaced with VRAS. The present experiment addresses primarily the first three issues within the framework of multiple resource theory. Ten

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subjects performed first and second order tracking tasks either alone or concurrently with a Sternberg Memory Search Task with a set size of three letters. In different conditions the memory search task was presented either auditorily (A) or visually (V), and responses were executed with either a speech response (S), or manually (M). These generated four input/output combinations: AS, VS, AM, VM, that could be defined in terms of an increasing degree of resource overlap with the VM tracking task.

The results were generally interpretable within the framework of multiple resource theory. (1) The effect of visual input competition was borne mostly by the perceptual/cognitive memory search task, while the effect of manual output competition was observed in the response-loading tracking task. The latter effect was amplified in second order tracking. (2) Task priorities exerted a reliable effect on performance, and this effect was greater as the tasks shared more common resources. (3) Tracking order exerted a negligible effect on the memory search task when the input/output modalities were separate. This finding is expected since the central processing codes of the two tasks are also separate (verbal vs. spatial). (4) Although clear performance differences were observed between i/o modality conditions, these were not reflected in the assessment of subjective workload ratings. (5) The reaction time error data provided support for the concept of S-C-R compatibility described by Wickens, Vidulich, Sandry, and Schiflett (1981): The verbal Sternberg task was performed best in the S-C-R compatible A/S condition and most poorly in the incompatible V/M condition under both single and dual task conditions. The findings, therefore, support the appropriateness of multiple resource theory for describing i/o modality effects. This suggests that dual task performance advantages can be obtained with VRAS technology, but that these advantages will be reflected differently in different tasks and be enhanced by increases in task difficulty.

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Introduction

In recent years rapid developments in the field of voice technol gy has rendered the incorporation of auditory displays and voice controls a viable alternative to the more conventional combination of visual displays with manual controls. The intuitive appeal of using alternative stimulus and response modalities in complex man-machine systems such as the aircraft cockpit or nuclear power consol that are presently overloaded with visual displays and manual controls, is probably sufficient to insure that future systems will incorporate auditory/speech (A/S) channels. However, intuition alone will not be sufficient to guarantee that A/S channels will be used optimally. The question of optimal use requires experimental research to be properly answered. A prime contention of this report is that such research can be efficiently and effectively performed within the framework of multiple resource theory.

Factors Influencing the Advantage of A/S Channels

It is possible to assign factors that influence the relative advantages or disadvantages of A/S channels to one of three general categories.

First, there are factors that are defined by unique constraints or "structural" limitations on modalities. For example, auditory input is commonly more serial and transient than is visual input. But, vision is more susceptible to degradation by anoxia and G-forces, and cannot readily be directed to different spatial locations in parallel. Continuous analog control of a dynamic system would probably be poorly

suited for speech control since the vocal apparatus produces continuous modulation with considerably less precision than does the hand. In contrast, operations involving the specification of a series of symbolic stimuli (i.e., digits, letters, or words) seem especially amenable to speech responses as opposed to manually operated keyboards. These and other similar concerns have been extensively treated by Lea (1978) and need not be elaborated upon here.

Second, the relationship between the central processing requirements of a task and its i/o modalities in single task performance may influence the relative advantage or disadvantage of the A/S channel in multi-task situations. An important dimension along which tasks differ concerns the type of coding (spatial or verbal) used. There is evidence that some mappings of i/o channels on tasks requiring a particular type of central processing are more efficient than others (e.g., Greenwald, 1970, 1979). Wickens, Vidulich, Sandry, and Schiflett (1981) have argued, on the basis of experimental data in the literature, that a unique compatibility relationship exists when verbal tasks are assigned to the A/S modes, and spatial tasks to V/M modes. This result has been confirmed in a recent investigation by Sandry and Wickens (EPL-ONR Technical Report 82-1, January, 1982).

Third, the relative advantage or disadvantage of the A/S channel is influenced by the relationship between the i/o modalities of a given task and those of competing tasks. This factor may be explained within the framework of resource theory (Navon & Gopher, 1979; Wickens, 1980), and this will now be considered.

Multiple Resource Theory

Multiple resource theory asserts that there are multiple "capacities" within the human processing system that may be assigned resource-like properties (allocation, flexibility, sharing). There are two basic implications of multiple resource theory when applied to time-sharing situations: (1) to the extent that two tasks demand separate rather than common resources, they will be time-shared efficiently; (2) to the extent that two tasks share common resources, decrements in the performance of one task will increase either as priorities are shifted to the other task, or as the other task is rendered more difficult in a manner demanding of those resources.

Summarizing a number of dual task investigations, Wickens (1980) has identified three information processing dimensions along which resources may be heuristically dichotomized: stages of processing (perceptual/central vs. response), modalities of input and response, and codes of perceptual and central processing (verbal vs. spatial).

The input/output modality (i/o) dimension is the obvious choice to be discussed in terms of the potential use of AS channels. Ideally, if one task which demands only visual input and manual responses is time-shared with another task which demands only auditory input and speech output, there would be no overlap of resources demanded and perfect time-sharing should be the result. This would predict that cross-modal time-sharing conditions (i.e., visual-auditory) would not only provide better time-sharing than intra-modal conditions, but would provide perfect time-sharing. While a few investigations have demonstrated the latter success in cross-modal conditions (Shaffer,

1975; Allport, Antonis, & Reynolds, 1972), a larger number of others have not (e.g., Treisman & Davies, 1973; Rollins & Hendricks, 1980; Isreal, 1980; Wickens, 1980). There are two primary factors which prevent this ideal state from being realized: (1) Competition for central processing resources, and (2) competition for resources of a "general" perceptual nature (Wickens, 1981).

Central processing operations refer to those processes such as memory operations, judgments, and transformations that play a role in most complex tasks of man-machine system operation, and are independent of the input or output channels employed for perception and response. One important issue appears to be the central processing codes (verbal or spatial) used in the processing of the information. The multiple resource model draws a major dichotomy between spatial and verbal codes of central processing (Wickens, 1981; Kinsbourne & Hicks, 1978). Logically then, two time-shared tasks with separate i/o configurations may still compete with each other if they both demand the same central processing resources. An example is provided by Treisman and Davies' (1973) finding of interference when two targets were searched for, each using a different input channel, but a common target code (e.g., spatial--experiment 1, verbal--experiments 2 & 3). Task interference was still observed. On the other hand, it is also possible for separate codes of central processing to provide nearly perfect time-sharing, so long as i/o modalities do not compete. An example of such a situation is provided by Henderson (1972) who demonstrated no interference between a verbal primary task with a visual/manual (V/M) i/o and a spatial V/M secondary task. (The two tasks did not require

any concurrent i/o processing). However, a verbal AS secondary task consistently interfered with primary task performance. In other words, separate coding dimensions were able to overcome the potential interference from the common i/o configurations (albeit perhaps only because of no concurrent input or output), but separate i/o could not eliminate the interference arising from common coding dimensions.

In addition to the competition for central processing resources, tasks with non-overlapping i/o configurations may also compete for common-"amodal" perceptual resources. More specifically, Wickens (1981) has argued that processing resources may be defined hierarchically. Thus, although separate, exclusive resources exist which cannot be transferred between the visual and auditory modalities, there also exists more general, cross-modal resources associated with the processing of either verbal or spatial information from both modalities. These resources would be sharable between the modalities of input but not between codes of processing. Cross-modal sharing of perceptual resources should be notable when the demands associated with the processing of information for one modality becomes extremely high. Under these circumstances, multiple resource theorists have suggested that resources usually associated with another task or modality are applied to the modality associated with the demanding task but at greately reduced efficiency (e.g., Navon & Gopher, 1979).

A large number of investigations have demonstrated, in one form or another, the advantage of cross-modal over intra-modal time-sharing with regard to the division of inputs over two sensory modalities. Fozard, Carr, Talland, and Erwin (1971) found that subjects searching

for a signal (i.e., three consecutive letters or digits) in two separate strings of mixed letters and digits performed better when one string was presented auditorily and the other visually as opposed to to the condition when both strings were presented visually. Results from Vinje (1972) showed that pilots in a simulated hover control task could control an auditorily displayed function combined with a visually displayed function better than when the two functions were both displayed visually on separate displays. Similar conclusions in a compensatory tracking task, presented auditorily or visually, were offered by Isreal (1980). Vinje (1972) concluded that the pilots were either controlling the auditory and visual functions in parallel, or that the switching rate between the auditory and visual displays was faster than the switching rates between the two visual displays. Also, the pilot subjects commented that workload seemed less in the cross-modality configuration. Treisman and Davies (1973) concluded that dividing inputs for two tasks across visual and auditory modalities allows subjects to use dedicated resources more efficiently. Rollins and Thibadeau (1973) found that although subjects were unable to process and store one verbal message while attending to another in a dichotic listening situation, they were able to process and store a larger portion of the contents of an equivalent visual message time-shared with an auditory message. Research by Rollins and Hendricks (1980) showed that subjects could process verbal material from both visual and auditory channels simultaneously without interference if the material presented visually required only semantic but not acoustic analysis. They concluded that acoustic analysis occurs

within the same system irregardless of the input modality.

Examining the utility of speech response systems, Kantowitz and Knight (1976) found that when a manual, rather than speech, response digit-identification task was time-shared with a tapping task, performance was impaired. McLeod (1977) found that a manual response two-choice tone identification task interfered with the production of responses for a time-shared continuous tracking task, but that a speech response two-choice tone identification task did not. Comparing speech to manual keyboard operation of a radio channel input time-shared with a VM tracking task, Mountford and North (1980) found that optimum time-shared performance for both tasks occurred when the speech response was used. Harris, Owens, and North (1978) arrived at a similar conclusion.

Examining the question of changing input and output modalities simultaneously, an investigation by Wickens and Harris (see Wickens, 1980) in which a VM tracking task was paired with a discrete verbal task employing four i/o configurations (AM, AS, VM, VS) produced results which suggested that task interference was a roughly additive combination of overlap of input and output modalities.

It is worth noting that such results are not confined to just visual and auditory input modalities. Research by Burke, Gilson, and Jagacinski (1980) demonstrated that using tactile rather than visual input on a primary tracking task allowed it to be more efficiently time-shared with a secondary VM tracking task.

The goal of the present experiment was to replicate and extend these results. Specifically, the present experiment investigates the effects of i/o overlap between a tracking task and a Sternberg memory

search task (Sternberg, 1969; 1975). The tracking task was always VM and was chosen because it typifies the type of continuous control required in many man-machine systems (such as driving a car, flying an aircraft, etc.). The Sternberg task was selected because it is easily presented in any of the four i/o configurations (AS, AM, VS, VM) and is a task with obvious central processing demands (e.g., memory retrieval, scanning). The correlation of performance measures of the retrieval speed of the Sternberg memory search task with the capacity of STM furthermore suggests that the former be representative of many tasks involving verbal working memory (Cavenaugh, 1972).

If multiple resource theory is appropriate, then as i/o overlap between the two tasks lessens (that is, as the secondary task changes from VM to VS and AM to AS) overall performance should improve; this much is only a replication of the work already mentioned. To provide a more rigorous test of the applicability of multiple resource theory, subjects' priorities between tasks are manipulated as well in the different i/o configurations. As the subject is instructed to consider either the tracking or the Sternberg and his primary task, multiple resource theory predicts that the biasing is accomplished by providing the primary task greater access to the common resources that are shared with the secondary task. In this case, as the amount of common resources between tasks are reduced (by reducing i/o overlap) the effect of changing the subjects' priorities should also be reduced (Navon & Gopher, 1979).

A second property of the present experimental manipulations extends the previous findings. As the tasks are time-shared with

different i/o modalities and different priorities, we also manipulate the difficulty of the tracking task by changing its control order. There are two reasons for this manipulation. (1) In terms of the predictions of multiple resource theory, we assume that as a task is made more difficult, it demands greater resources of one sort or another for its performance. The precise identity of these resources should then be revealed by evaluating the interaction of shared vs. separate modalities of input and/or output, with task difficulty. If an interaction occurs with input, then the resource demands of the manipulation may be presumed to be perceptual/central. If, on the other hand, the interaction is with output, then the resource demands associated with the difficulty increase are response related. With regard to the particular difficulty variable (i.e., control order) selected for this investigation, there remains some uncertainty concerning the precise locus of effect (Wickens, Gill, Kramer, Ross, & Donchin, 1981; Wickens & Derrick, 1981). Clear evidence in these studies was obtained for "early" processing demands associated with higher order control. Other investigators (e.g., Navon & Gopher, 1980) have argued that the locus of effects is in response processes.

(2) At a more applied level, it is important in general for systems designers to know how the relative advantages of separate i/o modalities are affected by variation in task load. Two alternative predictions may be made. (a) As task load increases, demanding more of the resources available, it may become more beneficial to use all resources available. Therefore, the advantage of separate i/o modalities will increase with demand. (b) As load becomes sufficiently

high, the operator may "regress" to an essentially single-channel mode of operation (Moray, 1981; Welford, 1976) in which case it really matters little along which channel alternative stimuli and responses are delivered, since they will be processed in serial fashion in any case.

Method: Experiment 1

Subjects

Ten male graduate and undergraduate students at the University of Illinois were recruited to serve in this experiment. All subjects were paid $3.00/hr, plus earned bonuses, for their participation.

Apparatus

The subjects were seated in a sound and light attenuated booth. The armrests on the subjects' seat were equipped with manual response devices. the left armrest was equipped with a spring-loaded dual-axis joystick to provide control input for the tracking task, while the right armrest was affixed with a two-button control panel for subjects' responses in the manual-response Sternberg conditions. The buttons were 1 cm^2 buttons located adjacent to each other with the right button slightly forward. They were designed to be used by the index and middle fingers of the subject's right hand.

Approximately 90 cm in front of the subject and below eye-level was the 10 cm x 8 cm display of a Hewlett-Packard Model 1330a CRT which was used to present all of the visual stimuli to the subjects. Auditory stimuli were delivered to the subjects via the right earcup in a set of headphones. Speech responses were articulated into a microphone mounted to the headset and positioned directly in front of

the subject's mouth.

A PDP 11/40 mini-computer was used to generate the stimuli and record the subject's performance. The computer was interfaced with a Hewlett-Packard display generator and a Measurement Systems, Inc. Model 521 control stick. Auditory stimuli were generated by a Centegram Corporation Mike-2 unit, interfaced to the PDP 11/40.

The subject and experimenter communicated by intercom operating through headsets.

Experimental Design

The experiment incorporated a within subjects procedure. Four major independent variables were manipulated.

(1) Sternberg Input Modality. The input to the subjects for the Sternberg task could be presented either visually (V) on the CRT display or auditorily (A) by the Mike-2 unit.

(2) Sternberg Output Modality. Subjects responded to the stimuli either manually (M) by pressing the buttons on the right armrest, or by speech (S) into the headset microphone.

Combining variables 1 and 2 generates the four Sternberg task configurations used in this experiment; auditory-speech (AS), auditory-manual (AM), visual-speech (VS), and visual-manual (VM).

(3) Tracking Order. The tracking task could have either of two possible types of control dynamics; first-order velocity control or second-order acceleration control. The task in either case was a single-axis compensatory tracking task displayed horizontally on the CRT screen. The display was driven by a random forcing function with an upper cutoff frequency of .32 Hz.

The four Sternberg configurations (AS, AM, VS, VM) and the two tracking conditions (1,2) were run in all possible single- and dual-task configurations.

(4) Bias. Th variable was of course manipulated only in dual-task trials. Subjects were instructed that in the dual-task trials they would be asked to bias their performance to favor one of the two tasks; either a pro-Sternberg bias (RT) or a pro-tracking bias (TK). As a guideline, subjects were told to try to give a 70%/30% division of available resources or effort to the high and low priority tasks, respectively.

Table 1 provides a summary of the resulting 22 unique trial types contained in one complete experimental block.

Experiment 1 was run over 5 sessions. Session 1, averaging between 60 and 90 minutes in length, was a general familiarization session. The four single-task Sternberg configurations were followed by 7 to 14 trials of single-task tracking. Finally, if time permitted, four dual-task trials pairing each of the Sternberg configurations with second-order tracking were presented. The exact number and type of trials run depended upon the individual subject's ability and experience.

Session 2 began with a few single-task tracking trials to refresh the subject's memory. Then a practice block using the same procedure as the experimental blocks was run. This means that on all of the dual task trials of this block, the subject was asked to bias dual-task performance toward one task or the other. Session 2 averaged 2 hours in length.

Table 1

The 22 Trial Configurations Comprising
1 Experimental Block in Experiment 1

(I) Single-Task Trials

A) Four types of Sternberg

(1) AS - auditory-speech
(2) AM - auditory-manual
(3) VS - visual-speech
(4) VM - visual-manual

B) Two types of tracking

(5) 1 - first order
(6) 2 - second order

(II) Dual-Task Trials

16 types of trials resulting from the complete crossing of the four Sternberg configurations, the two tracking conditions and the two levels of bias (RT, pro-Sternberg or TK, pro-tracking).

Sternberg Configuration	Tracking order	Bias: RT	Bias: TK
AS	1	(7) AS-1-RT	(8) AS-1-TK
	2	(9) AS-2-RT	(10) AS-2-TK
AM	1	(11) AM-1-RT	(12) AM-1-TK
	2	(13) AM-2-RT	(14) AM-2-TK
VS	1	(15) VS-1-RT	(16) VS-1-TK
	2	(17) VS-2-RT	(18) VS-2-TK
VM	1	(19) VM-1-RT	(20) VM-1-TK
	2	(21) VM-2-RT	(22) VM-2-TK

Sessions 3, 4, and 5 each consisted of one complete experimental block. For Session 3, each subject was administered a unique random order of the 22 trial configurations. In Session 4, this order was reversed. Session 5 started with trial 12 of day 3. This was followed by an alternating sequence of the trials preceding and following trial 12 of session 3 (i.e., 12, 13, 11, 14, 10, 15, ...). Sessions 3, 4, and 5 each averaged 2 hours to complete.

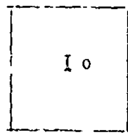
Procedure

Prior to each individual trial, the experimenter informed the subject of the trial type. When the subject indicated that he was ready, the experimenter started the trial. If the trial contained a Sternberg task it began with a presentation of the three letter memory set via the appropriate stimulus modality (V or A). Ten seconds was provided for encoding of this set, before the task(s) began. The subject would then perform the task(s) for a 2 minute long trial. Figure 1 illustrates the format of the single task Sternberg and tracking displays and of the dual-task display.

Following the trial the subject received feedback regarding his performance. For the three experimental sessions, if a given trial's performance met or exceeded the subject's previous performance on that trial type, then the subject was awarded a 7 1/2 cent bonus.

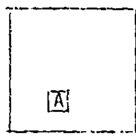
At the end of the trial the experimenter would record the following data as appropriate; (1) the number of correct vs. the number of incorrect Sternberg responses (used to calculate the percent error statistic), (2) the mean latency for correct Sternberg responses, (3) the RMS error for the tracking task, (4) the number of speech responses

a) <u>Single-Task Tracking Display</u> (or dual-task with auditory Sternberg)



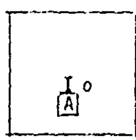
(The subject's task consisted of trying to center the circle onto the line, which remained stationary, through use of the left-hand joystick.)

b) <u>Single-Task Visual Sternberg</u>



(The subject's task was to respond as quickly as possible whether or not the letter in the box was in the memory set. Response could be manual (M) or speech (S). The letter terminated with the response.)

c) <u>Dual-Task Tracking and Visual Sternberg</u>



(Subjects would simultaneously perform tasks a and b.)

FIGURE 1 - Typical visual displays. (Note, in the case of a single-task auditory (A) Sternberg the CRT would be blank.)

not understood by the recognition device, and (5) the number of Sternberg errors due to acoustic confusion of the auditory stimuli.

The importance of the last measure is a consequence of the fact that the letter stimuli for the auditory Sternberg were trained into the Mike-2 unit in a fairly noisy environment. As a result, all subjects made occasional errors because of an inability to discriminate between acoustically confusable stimuli (e.g., A & K, P & B). Such errors are data-limited in nature, being unrelated to the demands of the concurrent task. They had no parallel in the visual Sternberg condition where stimuli were easily discriminable. Consequently, to provide a better estimate of the relative processing demands of the two input modalities, these acoustic errors were subtracted out to provide a corrected % error.

Results: Experiment 1

Three aspects of the results are relevant: (1) Single task performance, (2) dual task performance, and (3) time-sharing efficiency as revealed by the analysis of decrement scores from single to dual task conditions. Average scores on the dependent measures are displayed in Table 2. Interpretation of both single and dual task performance on the Sternberg task is complicated by hardware-induced timing differences between Sternberg configurations. That is, differences in human processing efficiency between modalities will invariably be confounded with differences in the timing logic employed to decide when an auditory stimulus is presented (onset or offset), and when a speech response is accepted (onset, offset, recognition). This issue will be dealt with below. Initially, however, we shall consider

Table 2

Mean Performance on the 22 Trial Configurations

(I) Single-task Performance

A) Tracking

	Mean RMS Error
1	120
2	205

B) Sternberg

	Corrected % error	$\overline{RT}$*
AS	0.5	1381
AM	0.9	793
VS	0.9	1166
VM	2.5	595

*msec

(II) Dual-task Trials

		Corrected % error	$\overline{RT}$	RMS error	RMS Error Dec.	RT Dec.
AS-1	RT	1.0	1419	141	22	38
	TK	0.7	1439	124	5	58
AM-1	RT	1.7	806	146	27	13
	TK	1.6	830	133	14	37
VS-1	RT	2.4	1253	137	18	87
	TK	2.6	1295	128	9	129
VM-1	RT	2.3	612	145	26	18
	TK	2.0	662	127	8	67
AS-2	RT	1.5	1430	225	18	49
	TK	1.3	1429	217	10	48
AM-2	RT	2.7	788	252	45	-5
	TK	2.4	828	240	33	35
VS-2	RT	2.6	1262	227	20	96
	TK	2.9	1314	209	2	148
VM-2	RT	2.7	622	253	46	27
	TK	2.5	685	234	27	90

the dual task decrements. These decrements do not encounter the same confounds as the absolute performance scores, since the difference in timing logic are automatically subtracted out.

Decrement Scores Analysis

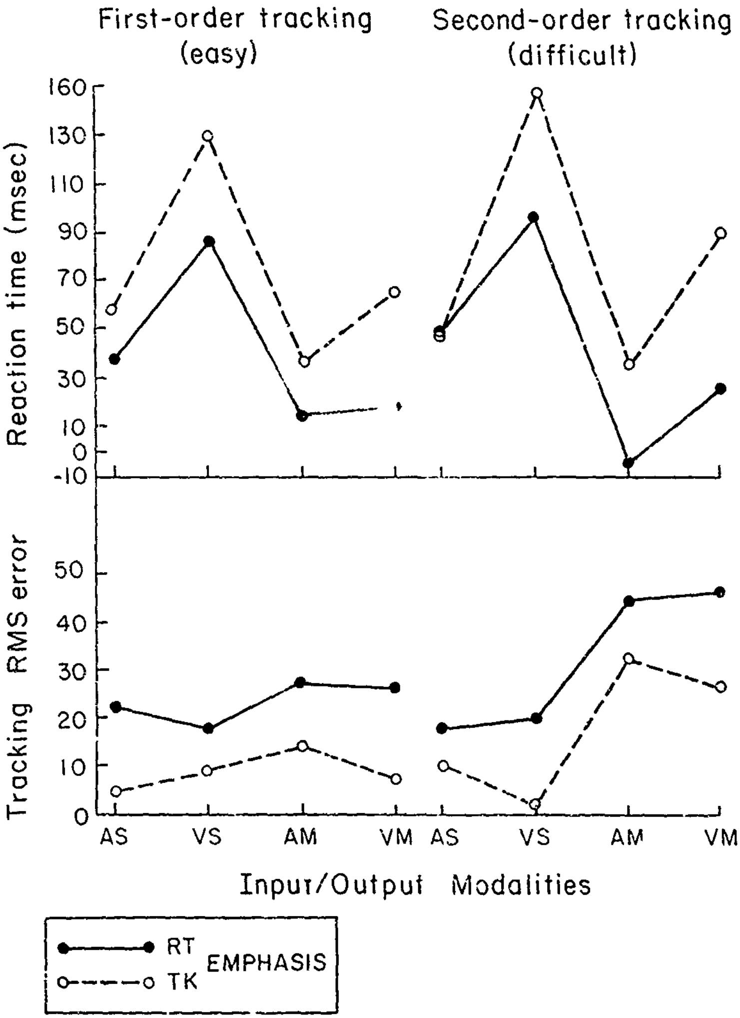
On all dual task trials the RMS error from the tracking task and the mean correct RT for the Sternberg task were transformed to decrement scores by subtracting the corresponding single task performance measure. Figure 2 presents the Sternberg and tracking task decrement scores expressed in units of milliseconds for the RT (top) and % scale for RMS error (bottom). The abscissa on each function portrays the effect of increasing i/o overlap from AS, on the left, to VM on the right. The left and right panels represent the easy (first-order) and difficult (second-order) level of tracking respectively, while the two functions within each panel represent the RT (solid lines) and tracking (dashed lines) emphasis conditions.

The data summarized in Figure 2 were subjected to two five-factor repeated measures ANOVAs, one for the RT latency data and one for RMS error. The factors were Sternberg input modality (A or V), Sternberg output modality (M or S), tracking difficulty (first or second), block (1, 2, or 3) and bias (RT or TK).

A number of observations may be made concerning the data in Figure 2. (1) For the most part, overlap of i/o modalities exerted their effects in the expected directions although the precise effects varied with the dependent measure studied. For RT performance in the Sternberg task, input overlap produced a significant increase in the RT decrement scores ($F_{1,9} = 8.9$, $p < .02$). This induces the pronounced Z shaped

Figure 2

RT (top) & Tracking (bottom) Decrements



functions in Figure 2. However, the effect of output overlap, while significant ($F_{1,9}$ = 9.3, $p < .02$), was directly contrary to the prediction; the manual condition showed a smaller RT decrement than the speech (34 vs 82, respectively). On the other hand, when tracking RMS error decrements are examined, sharing of output modalities was very disrupting ($F_{1,9}$ = 36.6, $p < .01$) while sharing input modalities exerted no significant interfering effects ($F_{1,9}$ = 0.7, $p > .4$).

(2) Increasing tracking difficulty from first-order to second-order failed to produce a reliable increase in the decrement in either RT ($F_{1,9}$ = 0.2, $p > .6$) or RMS error ($F_{1,9}$ = 1.5, $p > .2$).

(3) Task bias produced a reliable effect, reducing the decrement for the dependent variable of whichever task was favored ($F_{1,9}$ = 15.1, $p < .01$ for RMS error decrements, and $F_{1,9}$ = 4.8, $p < .05$ for the RT decrements).

(4) Practice block failed to effect the decrements in either RT or RMS error ($F_{2,18}$ = 0.1, $p > .8$, and $F_{2,18}$ = 0.8, $p > .4$, respectively). (Block is not displayed on Figure 2, but was included in the analysis to evalute practice effects.)

(5) A number of interactions among the manipulations were found. When RT decrements were examined, input modality was found to interact with bias ($F_{1,9}$ = 61.8, $p < .01$). The effect of changing the bias was apparently greater in the shared, visual input conditions than in the separated auditory input conditions. This is reflected in Figure 2 where the emphasis curves of the RT data are always distinct and roughly parallel but are more separated in the VS and VM conditions. This finding is also consistent with reports from a number of subjects

that biasing was easier to accomplish in the shared visual input conditions because it only required that the subject change the direction of fixation from one part of the visual display to the other. While such fixation changes were not sufficient to bring the non-emphasized task out of foveal vision, they apparently were successful as orienting or focussing strategies.

In the RMS error decrement analysis, two interactions were found to be significant. Output modality interacted with both tracking difficulty ($F_{1,9} = 22.2$, $p < .01$) and block ($F_{2,18} = 7.3$, $p < .01$). The interaction between output and tracking difficulty reflected the fact that in the manual condition increasing tracking difficulty from first to second order doubled the RMS error decrement (from 19 to 38) while in the speech condition increasing the tracking difficulty actually decreased the decrement by one percentage point (from 13 to 12). The output by block interaction is displayed in Table 3. It seems that practice had both a lesser and later effect in reducing RMS error decrements in the speech output conditions. With neither dependent variable did bias and tracking difficulty show any interaction with each other, or jointly with any other manipulated variable.

The decrement score results may also be represented in the form of Performance Operating Characteristic curves, or POCs (Norman & Bobrow, 1975; Navon & Gopher, 1979). The POC curves for the two tracking orders across the four Sternberg configurations are displayed in Figure 3. The utility of the speech (right panels), as opposed to the manual (left panels), output in the Sternberg task is clearly indicated by the

Table 3

Mean RMS Error Decrement as a Result of Output Modality and Experimental Block

Output Modality		Block 1	Block 2	Block 3
	M	35	24	26
	S	14	15	10

Table 4

Mean RMS Error as a Result of Sternberg Output Modality and Practice

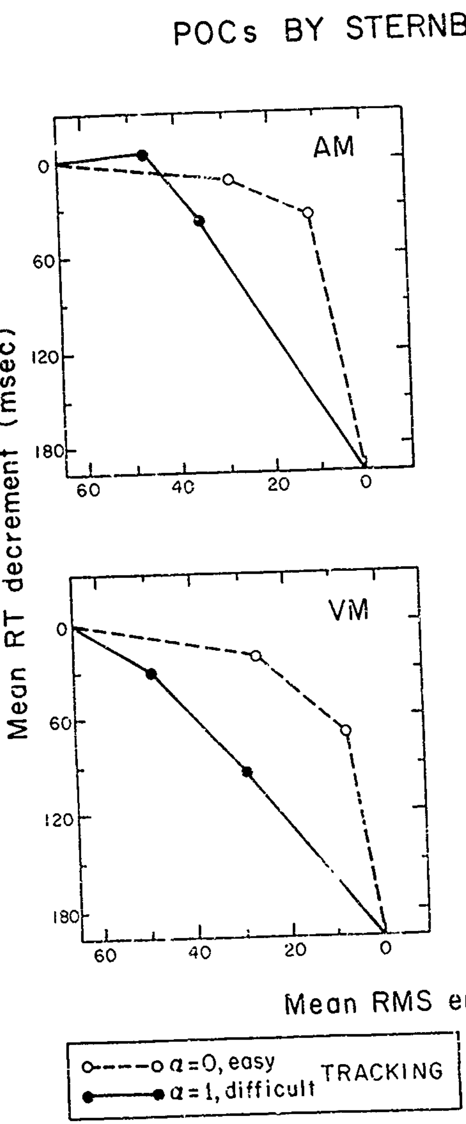
Output Modality		Block 1	Block 2	Block 3
	M	208	188	178
	S	188	178	161

Table 5

Corrected % Error Scores for the Four Sternberg Configurations (Dual Task)

Output Modality		Input Modality V	Input Modality A
	M	2.4	2.1
	S	2.6	1.1

Figure 3


POCs BY STERNBERG CONDITION
AM
AS
VM
VS
0
60
120
180
60
40
20
0
Mean RT decrement (msec)
Mean RMS error decrement
α=0, easy
α=1, difficult
TRACKING

close proximity of curves for differing tracking orders in the AS and VS conditions. In contrast, in the AM and VM conditions, increasing tracking order substantially depressed the subject's ability to time-share the tasks. This is indicated by the solid lines, portraying second-order performance, lying closer to the origin than the dotted lines, portraying first order performance. Within the speech output condition there is an advantage to using auditory input indicated by the relatively high and box-like shape of the functions in the AS condition compared to the shallowness of the functions in the VS condition.

Single-Task Sternberg RT Data

The differences in timing logic between the A & V input modalities and M & S output modalities resulted in quite diverse baseline measures for the four Sternberg configurations. The baseline mean correct-response RTs for the four Sternberg conditions are displayed in Table 2.

The timing logic differences resulted from the fact that verbal information transmitted acoustically requires time for enough information to be presented so that an accurate discrimination can be made. Since the RT timing interval began with the onset of the stimulus and ended with the machine identification of the response, both auditory input and speech response were at an intrinsic disadvantage, unrelated to human processing delays when compared to their visual and manual counterparts.

A three factor ANOVA was used to analyze the single task RT data. The three factors were input modality, output modality, and block. All

three factors had significant main effects ($F_{1,9} = 77.0$, $p < .01$, $F_{1,9} = 355.0$, $p < .01$, and $F_{2,18} = 14.9$, $p < .01$, respectively); visual input w s faster than auditory, manual response faster than speech, and subject improved with practice. No interactions were significant.

Dual-Task RT Analysis

A five-factor ANOVA of the same type used to analyze the RT decrements was used on the raw correct response RT data (second column of Table 2 bottom). Significant main effects were observed for Sternberg input modality ($F_{1,9} = 95.8$, $p < .01$), Sternberg output modality ($F_{1,9} = 535.3$, $p < .01$), block ($F_{2,18} = 9.2$, $p < .01$), and bias ($F_{1,9} = 4.8$, $p < .05$). Tracking difficulty failed to reach significance ($F_{1,9} = 0.2$, $p > .6$). The significance of input and output modality variables are dominated by the timing base-line differences mentioned in the single-task RT analysis, and are therefore less informative concerning dual task interference than the same effects found in the RT decrement analysis. The fact that block is significant in this analysis but not in the RT decrement analysis seems to suggest that practice affects primarily the performance of the individual tasks and not so much their time-sharing efficiency. The significance of bias, once again, reflects the subject's ability to improve performance of one task by favoring it over another.

The interaction found in the RT decrement analysis (input by bias) was also found in this analysis ($F_{1,9} = 61.8$, $p < .01$) and may be interpreted in the same manner as before. In addition, one interaction not significant in the RT decrement analysis was found significant in the present one; Sternberg output modality by block ($F_{2,18} = 4.4$, $p <$

.03). This interaction reflects the greater influence of practice on the speech compared to the manual response mode.

Dual-Task RMS Error Analysis

A five-factor analysis of the same type used to analyze the RMS error decrements was used on the raw dual task RMS error data. Significant main effects were observed with Sternberg output modality ($F_{1,9}$ = 36.6, $p < .01$), tracking difficulty ($F_{1,9}$ = 43.6, $p < .01$), block ($F_{2,18}$ = 59.1, $p < .01$), and bias ($F_{1,9}$ = 15.1, $p < .01$). Subjects performed better when: the Sternberg output modality was speech, when the tracking was first-order, when they had more practice, or when bias emphasized the tracking task. Sternberg input modality exerted no significant effect ($F_{1,9}$ = 0.7, $p > .4$). There were three signficant interactions. Output modality interacted with tracking difficulty ($F_{1,9}$ = 22.2, $p < .01$). The increase in tracking difficulty had a much more pronounced effect in the manual response condition, an effect noted in the decrement analysis. Output modality also interacted with block ($F_{2,18}$ = 7.3, $p < .01$). These data are displayed in Table 4. Practice seems to have a more dramatic effect in manual response conditions, an effect also noted in the decrement analysis (Table 3). Block also interacted with tracking difficulty ($F_{2,18}$ = 5.8, $p < .02$). Practice caused a greater improvement in second-order tracking.

Comparing these results to the results of the RMS error decrement analysis reviewed earlier reveals some interesting phenomena. Both analyses found similar significant effects for Sternberg ou put modality, bias, output by tracking interaction, and output by block

interaction. However, tracking difficulty was significant in the raw RMS error analysis, but not significant in the RMS error decrement analysis ($F_{1,9}$ = 1.5, p > .2). Since the decrement score is simply the dual task score subtract the corresponding single task score, this indicates that while changing from first- to second-order tracking will increase total error, it does so to a roughly equivalent degree, for both single task and dual task trials. This effect is consistent with that obtained by Wickens and Derrick (1981) and is accounted for by the fact that the central processing demands imposed by increased tracking are primarily associated with spatial processing, while those of the Sternberg task are of course verbal.

Sternberg Error Analysis

In the single task Sternberg condition, both input modality ($F_{1,9}$ = 8.6, p < .02), and output modality ($F_{1,9}$ = 7.8, p < .03) exerted significant effects on the corrected % err scores. The auditory input was superior to the visual input, and the speech output superior to the manual output. Block failed to reach significance ($F_{2,18}$ = 0.7, p > .4). The interaction between input and output was also significant ($F_{1,9}$ = 38.4, p < .01). Table 2 displays the error rate for this interaction. The superiority of speech over manual response was much more pronounced in the visual input condition.

In the dual task trials the auditory input conditions once again had a significantly lower error rate than the visual input conditions ($F_{1,9}$ = 11.3, p < .01), while the output modality effect was not reliable. The interaction between input and output was again significant, ($F_{1,9}$ = 10.8, p < .01). However, this time the pattern is

somewhat different than in the single task case. This pattern, shown in Table 5 suggests that in the visual input conditions, output modality exerted a relatively small effect favoring the manual output while the auditory input conditions displayed a larger effect favoring the speech output. The only other significant interaction was a three-way interaction between input, output, and block ($F_{2,18} = 4.4$, $p < .03$). No consistent trends are evident to account for this interaction.

Speech Recognition Data

The Mike-2 unit averaged 0.84% failures in recognition of the subject's speech responses over the three experimental blocks. The percentages for individual subjects ranged from a low of 0.11% failure to a high of 3.25% failure.

Method: Experiment 2

Subjects

Nine of the ten subjects from Experiment 1 were used in this experiment.

Apparatus

This was identical to that of Experiment 1.

Experimenter Design

The experiment used the same Sternberg and tracking tasks as Experiment 1. However, no biasing of priorities was used. Subjects were asked to use a 50/50 division of emphasis between the two tasks in the dual-task configurations. The resulting 14 trial configurations are displayed in Table 6.

Table 6

The 14 Trial Configurations Comprising

1 Experimental Block in Experiment 2

(I) Single-Task Trials

A) Four types of Sternberg

(1) AS
(2) AM
(3) VS
(4) VM

B) Two types of tracking

(5) 1
(6) 2

(II) Dual-Task Trials

(7) AS - 1
(8) AM - 1
(9) VS - 1
(10) VM - 1

(11) AS - 2
(12) AM - 2
(13) VS - 2
(14) VM - 2

Procedure

The general scheme for the ratings was inspired by Higgens (1979). Subjects in the subjective ratings task were instructed that single-task second-order tracking was to be considered a "standard" and was arbitrarily assigned a difficulty rating of 10.

Fifteen seconds of the standard task was performed to start each trial. Following the standard, one of the 14 trial configurations was run for the full two minutes. (The single-task second-order trial was an exception to this routine. This was run just to get a baseline measure and was not rated by subjects since it was arbitrarily assigned a rating of 10. Consequently, this trial was run without the 15 second preview.) Following the completion of the full trial, subjects were asked to rate that trial's difficulty in terms of resources demanded and effort expended, relative to the standard's difficulty rating of 10. Twice as difficult as the standard was to be assigned a rating of 20, half as difficult a 5, and so on. The subject's accuracy, RT, and error were recorded the same way as in Experiment 1.

The session consisted of two complete experimental blocks, a total of 28 trials. Each subject received a unique random order of trial configurations for the first block, which was reversed for the second block. There was a short rest break between the two blocks.

Results: Experiment 2

The data of interest in experiment 2 are the subjective ratings data. Analysis of the performance measures were performed, but only used to check that performance was comparable to experiment 1. The

performance means are included with the mean ratings in Table 7.

A four-factor ANOVA was used to analyze the subjective ratings data. The four factors were: Sternberg input modality (A or V), Sternberg output modality (M or S), tracking difficulty (no tracking = 0, first-order = 1, second-order = 2), and block (1 or 2). (Note - no single task tracking was included in this analysis.) Significant main effects were obtained for tracking difficulty ($F_{2,16} = 42.2$, $p < .01$) and block ($F_{1,8} = 8.7$, $p < .02$). Subjects rated higher difficulty as tracking was added or made more difficult and tended to rate lower in the second block. Neither input modality ($F_{1,8} < 1$) nor output modality ($F_{1,8} < 1$) had a significant effect on the subject's ratings. No interaction was significant. Perhaps the most noteworthy aspect of the data presented in Table 7, is that the difficulty of the VM condition, rated lowest of the four i/o modes in single task performance, progressively increased in its rating relative to the other modes as task demands were successively increased. However, as noted, this effect was not statistically reliable.

Discussion

The present research was undertaken to examine the appropriateness of multiple resource theory in describing performance across task combinations with differing degrees of i/o overlap. The assumption was made that if the multiple resource model adequately described the subjects' performance then it could be used to suggest guidelines for the use of speech recognition and synthesis technology to exploit the AS channel optimally. However, before specifying any guidelines there

Table 7

Mean Performance on the 14 Trial Configurations

(I) Single Task Trials

(A) Tracking

	RMS Error	Mean Ratings
1	130	6.9
2	215	--

(B) Sternberg

	Corrected % Err	$\overline{RT}$	Mean Ratings
AS	0.4	1397	8.0
AM	1.2	845	7.4
VS	2.2	1203	6.4
VM	0.8	615	5.5

(II) Dual Task Trials

		Corrected % Err	$\overline{RT}$	RMS Error	Mean Ratings
AS	1	0.1	1474	146	15.1
	2	0.2	1488	234	19.8
AM	1	0.3	833	146	15.7
	2	2.3	835	253	19.1
VS	1	0.2	1349	145	15.1
	2	0.2	1333	232	19.1
VM	1	0.2	696	141	14.6
	2	0.2	703	256	22.6

are seven aspects of the research findings that warrant review; processing stage effects, tracking difficulty effect, bias effects, S-C-R compatibility, practice effects, timing logic considerations, and subjective difficulty ratings.

Processing Stage Effects

An interesting characteristic of the results concerns the differential effects of input as opposed to output overlap. When input modalities overlapped (i.e., the Sternberg task had visual input) the RT decrements increased significantly but the RMS error decrements did not. On the other hand, when output modalities were shared (i.e., the Sternberg had manual output) RMS error decrements increased while RT decrements actually decreased relative to the speech conditions. This asymmetry cannot be attributed to a primary-secondary task difference since it was observed under both conditions of task priorities. A plausible hypothesis is that the asymmetry relates to the locus of individual task demands: Tracking, a continuous task with relatively heavy response components is disrupted by competition for output resources. The Sternberg task is primarily a perceptual/cognitive task which demands output resources only occasionally for brief moments. Consequently, it is not surprising that RT decrements increase when competition for resources at the earlier input stage is highest (i.e., when the Sternberg has visual inputs). This account does not explain why the RT decrements actually decreased in the manual Sternberg conditions where presumably the competition for output resources was high. However, this topic will be dealt with in the next section. At the moment, it suffices to say that the stage of greatest processing

demands of a task influences the relative advantage of separate input/output channels, and the task that has the greatest demands at a given stage, bears the greatest cost of shared channels.

Tracking Difficulty Effects

The main effect of tracking order on the interference between the tracking and memory search task was not reliable. This lack of effect was observed despite the fact that higher order tracking is more difficult, generates greater error and, in Experiment 2 was rated as subjectively more difficult. On the other hand, the absence of a main effect of this sort is compatible both with the previous results of Wickens and Derrick (1981), and with multiple resource theory. Increasing tracking order imposes its primary demands upon spatial central processing, while the memory search task has perceptual/central components that are verbal in nature. Separate resources underlie the two, so little competition is observed. In fact, such competition will only be observed to the extent that the Sternberg task is altered so as to demand resources also used in higher order control. This is apparently the case when a manual Sternberg response is required. Under these conditions, increasing control order does increase resource competition (see Figures 2 & 3).

This effect, however, identifies an apparent inconsistency between the present results and those obtained by Wickens and Derrick. The latter study concluded, on the basis of interactions between Sternberg task difficulty variables and tracking order, that the locus of effect of second order tracking was on perceptual/central resources. The present investigation obtains little reliable evidence of this effect,

(although the non-significant ($p < .08$) interaction between input modality and tracking order for RT was in the right direction, indicating a greater cost to RT performance in second order tracking in the visual condition). On the other hand, Wickens and Derrick did not obtain evidence for response loading effects by manipulating Sternberg response demands, while the present study did find such effects by changing Sternberg response modality.

The source of this potential inconsistency between the two investigators is not entirely clear. The different methodologies employed may have been responsible (increasing Sternberg difficulty at a given stage, versus changing Sternberg modality at a given stage). A second potential source of differences is more plausible and relates to subjects' strategies. Second order control may be accomplished by altering processing at any processing stage (Wickens & Derrick, 1981). It is possible that "early processing" strategies were adopted to a greater extent in the previous study while "late processing" strategies predominated in the present one. Further research will be necessary to resolve these potential inconsistencies.

Perhaps the most dramatic means of describing the overall influence of difficulty is by reference to Figure 3, in which the total cost to performance of higher order tracking on both tasks is observed in the separation of the two POCs. This cost, substantial with the manual response conditions, is all but eliminated when the speech response is employed.

One issue concerns why costs of increasing control order in the manual response condition were borne only by the tracking and not by

the RT task. Given the nature of the tasks, a plausible explanation relates to the fact that the tracking task is continuous, while the Sternberg task is discrete. We assume that a resource allocation policy was adopted by the subjects which provided the Sternberg task the manual response resources it needed on a momentary basis. For these brief moments the needs of the Sternberg task were entirely satisfied, independent of control order, while the tracking task did without. The end result was the inflation of RMS error decrements (and more so in second order tracking when response resources were in greater demand) with no corresponding effect on RT decrements. This policy was constant across allocation conditions. This interpretation may also explain the decrease in RT decrements resulting from manual output relative to speech output. If we assume that the total processing demands of a simple button press are less than the demands of speech production of one word, then it is plausible that an allocation policy as just described would result in lower RT decrements for the manual conditions.

Bias Effects

A second basic prediction of multiple resource theory concerns the effect of changing task biases. As with task difficulty, as the amount of common resources are reduced, performance should become more insensitive to the operation of the bias variable. There was, of course, a reliable main effect of bias on both dependent variables and a reliable increase in bias during the visual input when RT was examined. Resources were shared to some extent between the tasks, and so could be employed to adjust, or "modulate" performance. The

question of which resources were shared is answered by examination of Figure 3. Here the bias effect (degree of shared resources), as reflected by the degree of separation between the two allocation points appears to be a monotonic function of resource overlap. The effect is minimal in the AS condition, largest in the VM condition, and of intermediate status in the two conditions in which a single modality is shared (AM and VS). Figure 4 presents this bias measure more directly as a function of the number of common i/o resources between tasks. The greater bias effect on RT in visual, as opposed to auditory input, was of course, discussed already in the context of the statistically reliable effects of this variable. One interesting feature revealed by Figure is that only when the visual modality is shared does the bias measure differentiate first from second order tracking. This provides some support to the assertion that perceptual resources are indeed in increased demand in second order control. These resources can then be shared between the tasks to a greater extent, under second order control with the visual input. Stated in different terms, the ability to allocate resources is facilitated by overlap of both input and output modalities (the increasing slope of both functions of Figure 4). The effect of overlapping input, moreover, is greater in second than in first order control.

A final issue concerns what resources were shared in the AS condition in which neither input nor central processing nor output resources were common between the two tasks. While the assertion that there is indeed minimal resource overlap is supported by the small bias effect and the high degree of time-sharing efficiency in this condition

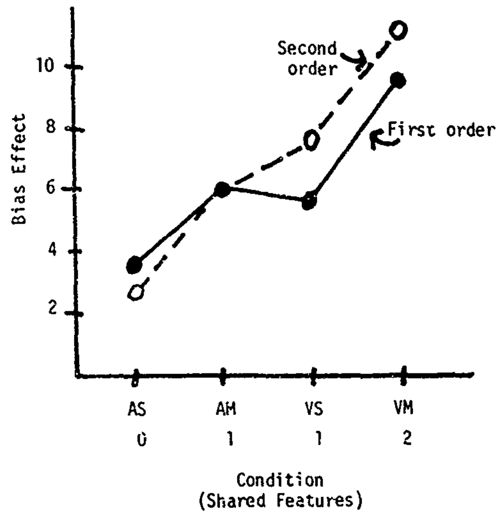


Figure 4. Magnitude of allocation bias effect as a function of shared I/O modalities.

(see Figure 3), there was some bias effect (albeit small), and efficiency was not perfect. The identity of these common resources cannot be ascertained definitely, but they are presumably related to either a "general" capacity for which all tasks completed, or a "general" perceptual or response capacity, available to both auditory and visual processes or to manual and vocal responses (Wickens, 1981).

S-C-R Compatibility

Wickens, Vidulich, Sandry, and Schiflett (1981) and Sandry and Wickens (1982) have outlined a theory of S-C-R compatibility that dictates the optimum assignment of input-output modalities to central processing codes. Briefly the theory asserts that verbal tasks will maximally benefit from auditory inputs and vocal responses, while spatial tasks will benefit most from a visual/manual i/o relationship. Sandry and Wickens (1982) provided strong support for this principle in a study in which both spatial and verbal tasks were assigned to all possible i/o combinations. The advantages to S-C-R compatible assignments (and costs to incompatible ones) were both observed, and were enhanced when the two tasks were performed concurrently with a flight task performed on an F-18 simulator.

The present investigation was not designed to investigate S-C-R compatibility explicitly since modalities were varied in assignment only to the verbal (memory search) task. Nevertheless, two characteristics of the results support the concept, one directly and the other indirectly. Direct support is offered by the corrected error data reported in Table 5, in which error rate was reduced as both the stimulus and the response were made S-C and C-R compatible,

respectively. The interaction in these data suggested error rate was lowest in the AS condition, that condition with maximum S-C-R compatibility for the verbal task employed.

When latency is examined, the support was less direct. As noted above, the largest latencies were observed in the AS condition and the shortest in the VM. However, these values were confounded by potential timing artifacts. In order to estimate the extent of these artifacts, a simple reaction time experiment was conducted in which the subject made a single response, either vocal or manual to a single stimulus. Under these conditions, we were confident that human processing RT differences between modalities should be in the order of only 30-40 msec (Fitts & Posner, 1967), and therefore that any residual differences would reflect differences in timing logic. The results indicated a 700 msec residual effect for the speech as opposed to the manual response. When this value is subtracted from the latency of the two speech conditions in Table 2, we note that <u>human</u> processing latency is, in fact, shorter in the speech, as opposed to the manual response condition, a finding that supports the principle of S-C-R compatibility. Similar contrasts were not made between auditory and visual input conditions.

<u>Practice Effects</u>

The finding that RT and RMS error are both reduced as a result of practice was, of course, to be expected. So was the fact that second order tracking benefitted more from practice than first order tracking. The fact that practice had a significant effect in the raw RT and RMS error for the dual task trials ($p < .01$ for both), but not in the

corresponding decrement scores ($p > .8$ and $p > .4$, respectively), is very interesting. It seems to imply that the improvement in dual task performance observed in this experiment was primarily the result of improvement in the skill of performing the individual tasks and not as a result of improvement in time-sharing abilities. However, there is one apparent exception to this conclusion that practice effects are localized in single task performance. In the dual task RMS error and RMS error decrements, the results were opposite, manual response configurations were aided more by practice than were the speech response configurations, a finding not observed in single task RT performance.

This result is entirely consistent with the predictions of multiple resource theory. The tracking task loads heavily on the response related resources. Consequently, the greatest overlap of resources, and therefore the greatest need of efficient time-sharing, is observed with Sternberg configurations involving manual responses. It follows logically that, insofar as time-sharing skills are concerned, practice should be of more value in the manual conditions where time-sharing is most important. This is precisely what was found to be true in both the dual task RMS scores and the RMS decrement analysis. Recall also that this was the condition in which resources were temporarily borrowed from the tracking task to meet the response needs of the RT task. Presumably with practice, subjects developed strategies whereby this borrowing would be accomplished with reduced disruption.

With regard to reaction time, there was little evidence of dual task effects that were not also obtained in single task conditions. Thus, while single and dual task RT both benefitted from practice, the decrement (difference between these) did not decrease with practice. There was apparently no time-sharing learning manifest in RT performance. The only suggested effect in this regard was the reliable ($p = .03$) interaction between output modality and block when dual task RTs were examined. Such an interaction, by definition, must imply the existence of a corresponding interaction either in the single task RTs or the decrements. Since in neither case, was a reliable interaction observed, the above effect is probably attributable to the statistical combination of two relatively weak effects. It is possible, however, that this effect might reflect the fact that initial practice might be more valuable for the speech response configurations as predicted by Cochran, Riley, and Stewart (1980). Cochran et al. (1980) pointed out that, although we are generally very facile with speech, most of us do not exert the strict control over our voice patterns as is required for optimal use of voice recognition technology. Therefore, an early advantage for the value of practice in the speech response conditions is to be expected. Why such an effect is visible in dual, but not single task performance is unclear, except perhaps assuming that the control demands resources, available in single task performance, but scarce under dual task conditions.

The present results provide a contrast with the findings of Gopher and North (1977). In pairing a tracking task with a digit-processing task and studying the effects of practice, Gopher and North (1977)

determined that: (1) Tracking performance improved as a result of improvement in the specific task of tracking, and (2) digit-processing improvement resulted from improved time-sharing. In the present study the opp site results were obtained: tracking in the manual, but not the speech ime-sharing condition benefitted insofar as time-sharing skills were co cerned, while the RT task benefitted equally in single and dual task pe formance. The reason for this inconsistency is not apparent. However the finding in the present study that the manual response conditi n provides greater evidence for time-sharing skill development is cons stent with arguments made by Damos and Wickens (1980) that a major c mponent of time-sharing skill relates to response strategies. As McLe d (1977) has pointed out, the intervening of manual responses is a m re critical element of dual task performance than is the interve ing of a manual and vocal response.

Timing Logic Considerations

An important concern in many design applications should be the relative speeds of response for different possible i/o configurations. In this respect, the present results seem to be perhaps discouraging for AS systems. Both auditory input and speech response slow the overall time of response to the Sternberg stimuli in this experiment. However, in many real world applications such may not be the case. In the present experiment advantages existed for the visual input and manual response which are unlikely to be duplicated in the real world. For example, subjects in this experiment kept their fingers poised directly above the response buttons. In many real world situations, an operator would have to search, or at least reach, for the proper

response control which may very well require a control movement which is more complex than a single button press. Also, in this experiment, the subject had the luxury of being able to focus visual attention on the only display which presented relevant information. In the real world, an operator is more likely to have to monitor a number of displays, and therefore may be looking elsewhere when a relevant stimulus is presented. So, although the limit on system response latency is shorter for the VM than for the AS condition, there are a number of factors which could outweigh this advantage in real world applications.

Workload Assessment Methodology: Subjective Ratings and Secondary Task Measures

The data also provide insight into the use of the Sternberg Memory Search Task as a workload assessment index (Micalizzi & Wickens, 1980; Wickens & Derrick, 1981; Schiflett, 1980). In their review of the Sternberg task as a workload index, Micalizzi and Wickens noted the inconsistent results often obtained with the auditory version of the Sternberg task when visual primary tasks were evaluated. The present data, evaluated in the tracking emphasis condition (this is the condition that is normally in force when the Sternberg task is the "secondary task") support these conclusions. When control order is increased, RT in the two auditory conditions actually decreases. RT in the visual condition on the other hand increases, a more expected effect (refer to Figure 2). This reinforces a point made by Wickens (1981b), when primary task workload is to be assessed by a secondary task, greater sensitivity will be obtained when the two tasks demand

common, rather than separate resources.

This research also examined the question of the utility of subjective ratings in evaluating tasks of varying difficulty. The technique used was a modification of Higgen's (1979) technique which proved to be useful in an earlier unpublished study by Wickens and Vdulich in discriminating between differences in tracking order and bandwidth. In the present experiment, the ratings failed to discriminate differences in Sternberg i/o modality, which proved to reliably alter objective performance. It may be that the technique used was insufficiently sensitive. Even if this is the case, however, these results argue against exclusive reliance upon subjective ratings to discriminate performance differences (Wickens & Derrick, 1981).

Conclusions

Returning to the question of guidelines for practicing designers, the present research encourages five conclusions:

(1) Gains in overall performance can be achieved by dividing i/o over AS and VM channels rather than by using only VM channels.

(2) The value of such division of i/o modalities becomes higher as overall task difficulty increases. Also, the effect increasing difficulty is consistent with the predictions of multiple resource theory given that the additional resources demanded by the increasing difficulty are specifiable.

(3) The AS configuration seems to be especially well-suited for the presentation and response to verbally coded items insofar as accuracy is concerned.

(4) The reduction in resource overlap resulting from the use of the AS channel can make overall performance more stable over changing subject priorities.

(5) In ideal circumstances, a VM configuration is likely to allow quicker responses than a AS configuration. However, ideal circumstances for the VM configuration are unlikely to be obtainable in most real world applications.

Probably even more important than these specific conclusions is the general finding that multiple resource theory provides an appropriate framework for the investigation of the utility of auditory recognition, speech synthesis technology. The present results are very encouraging for further work in the same vein investigating more fully such topics as the effects of S-C-R compatibility on the time-sharing of tasks and the effects of practice on the different i/o configurations.

References

Allport, D.A., Antonis, B., & Reynolds, P. On the division of attention: A disproof of the single channel hypothesis. Quarterly Journal of Experimental Psychology, 1972, 24, 225-235.

Burke, M.W., Gilson, R.D., & Jagacinski, R.J. Multi-modal information processing for visual workload relief. Ergonomics, 1980, 23, 961-975

Cavanaugh, J.P. Relation between the immediate memory span and the memory search rate. Psychological Review, 1972, 79, 525-530.

Cochran, D.J., Riley, M.W., & Stewart, L.A. An evaluation of the strengths, weaknesses, and uses of voice input devices. Proceedings of the 24th Annual Meeting of the Human Factors Society, Los Angles, 1980.

Damos, D.L. & Wickens, C.D. The identification and transfer of time-sharing skills. Acta Psychologia, 1980, 46, 15-39.

Fitts, P.M. & Posner, M.I. Human Performance. Belmont, Calif.: Brook/Cole, 1967.

Fozard, J.L., Carr, G.D., Talland, G.A., & Erwin, D.E. Effect of information load, sensory modality, and age on paced inspection performance. Quarterly Journal of Experimental Psychology, 1971, 23, 304-310.

Gopher, D. & North, R.A. Manipulating the conditions of training in time-sharing. Human Factors, 1977, 19, 583-593.

Greenwald, A. Sensory feedback mechanisms in performance control. Psychological Review, 1970, 77, 73-79.

Greenwald, A. Time-sharing, ideomotor compatibility, and automaticity. Proceedings of the 23rd Annual Meeting of the Human Factors Society, 1979.

Harris, S., Owens, J., & North, R. A system for the assessment of human performance in concurrent verbal and manual control tasks. Behavior Research Methods and Instrumentation, 1978, 10, 329-333.

Henderson, L. Spatial and verbal codes and the capacity of STM. Quarterly Journal of Experimental Psychology, 1972, 24, 485-495.

Higgens, T.H. A systems engineering evaluation method for piloted aircraft and other man-operated vehicles and machines. Department of Transportation, Federal Aviation Administration Systems Research and Development Service. Technical Report FAA-RO-78-78, September, 1979.

Isreal, J. Structural interference in dual-task performance: Event-related potential, behavioral and subjective effects. Unpublished doctoral dissertation, University of Illinois, 1980.

Kantowitz, B.H. & Knight, J.L., Jr. Testing tapping time-sharing, II: Auditory secondary task. Acta Psychologia, 1976, 40, 343-362.

Kinsbourne, M. & Hicks, R. Functional cerebral space. In J. Requin (Ed.), Attention and Performance VII, Hillsdale, NJ: Erlbaum, 1978.

Lea, W. (Ed.) Trends in Speech Recognition. Englewood Cliffs, NJ: Prentice Hall, 1978.

McLeod, P. A dual task response modality effect: Support for multiprocessor models of attention. Quarterly Journal of Experimental Psychology, 1977, 29, 651-667.

Micalizzi, J. & Wickens, C.D. The application of additive factors methodology to workload assessment in a dynamic system monitoring task. University of Illinois Engineering Psychology Lab., Technical Report EPL-80-2/ONR-80-2, December, 1980.

Moray, N. The role of attention in the detection of errors and the diagnosis of failures in man-machine systems. In J. Rasmussen and W.B Rouse (Eds.), Human Detection and Diagnosis of System Failures, New York: Plenum, 1981.

Mountford, S.J. & North, R.A. Voice entry for reducing pilot workload. Proceedings of the 24th Annual Meeting of the Human Factors Society, Los Angeles, 1980.

Navon, D. & Gopher, D. On the economy of the human processing system. Psychological Review, 1979, 86, 214-255.

Navon, D & Gopher, D. Interpretations of task difficulty in terms of resources: Efficiency, load, demand, and cost composition. In R. Nickerson (Ed.), Attention and Performance VIII. Englewood Cliffs, NJ: Erlbaum, 1980.

Norman, D.A. & Bobrow, D.G. On data-limited and resource-limited processes. Cognitive Psychology, 1975, 7, 44-64.

Rollins, H.A. & Hendricks, R. Processing of words presented simultaneously to eye and ear. Journal of Experimental Psychology: Human Perception and Performance, 1980, 6, 99-109.

Rollins, H.A. & Thibadeau, R. The effects of auditory shadowing on recognition of information received visually. Memory and Cognition, 1973, 1, 1964-168.

Sandry, D. & Wickens, C.D. S-C-R compatibility and resource competition in flight performance: The effects of different input and output modalities for verbal and soatial tasks. University of Illinois Engineering Psychology Lab., Technical Report EPL-82-1/ONR-82-1, January, 1982.

Schiflett, S.G. Evaluation of a pilot workload assessment device to test alternate display formats and control handling qualities, Naval Air Test Center Technical Report, 1980, SY-33R-80.

Shaffer, L.H. Multiple attention in continuous tasks. In P.M. Rabbitt & S. Dornic (Eds.), Attention and Performance V, London: Academic Press, 1975.

Sternberg, S. The discovery of processing stages: Extensions of Donder's method. Acta Psychologia, 1969, 30, 276-315.

Sternberg, S. Memory scanning: New findings and controversies. Quarterly Journal of Experimental Psychology, 1975, 27, 1-32.

Treisman, A. & Davies, A. Divided attention to eye and ear. In S. Kornblum (Ed.), Attention and Performance IV, New York: Academic Press, 1973.

Vinje, E.W. Flight simulator evaluation of audio displays for IFR hover control. Proceedings of the Eight Annual Conference on Manual Control, 1972.

Welford, A.T. Skilled Performance. Perceptual and Motor Skills. Glenview, Illinois: Scott, Foresman, and Company, 1976.

Wickens, C.D. The structure of attentional resources. In R. Nickerson (Ed.), Attention and Performance VIII, Engelwood Cliffs, NJ: Lawrence Erlbaum 1980.

Wickens, C.D. Processing resources in attention, dual task performance, and workload assessment. University of Illinois Engineering-Psychology Lab., Technical Report EPL-81-3/ONR-81-3, July, 1981.

Wickens, C.D. Workload: In defense of the secondary task. Personnel Selection and Training Bulletin, 1981, 2, 119-123 (b).

Wickens, C.D. & Derrick, W. The processing demands o. higher order manual con rol: Application of additive factors methodology. University of Ill nois Engineering-Psychology Lab., Technical Report EPL-81-1/ONR-81-1, Mar:h, 1981.

Wickens, C.D., Gill, R., Kramer, A., Ross, W., & Donchin, E. The processing demands of higher order manual control. Proceedings, 17th Annual NASA Con'erence on Manual Control, Los Angeles, Calif., June, 1981.

Wickens, C.D., Vidulich, M., Sandry, D., & Schiflett, S. Factors influencing the performance advantage of speech technology. Proceedings, 25th Annual Meeting of the Human Factors Society, 1981.

Speech Recognition Data
(of the subject's responses by the MIKE unit)

S #	# of Probes	# Responses not understood	% Failure
1	900	7	0.78
2	860	28	3.25
3	920	3	0.33
4	887	1	0.11
5	939	3	0.32
6	928	21	2.26
7	868	2	0.23
8	912	1	0.11
9	959	8	0.83
10	908	2	0.22
Totals	9081	76	8.44
Means	908.1	7.6	0.84

Auditory Recognition Data
(of the MIKE unit's stimuli by the subjects)

S #	Visual Errors (Processing Errors)	Total Auditory Errors (Processing & Data-limited)	Auditory Confusions (Data-limited Errors)	Net Auditory Errors (Processing Errors)
1	21	34	16	18
2	27	24	12	12
3	28	48	27	21
4	19	68	48	20
5	15	45	34	11
6	26	22	9	13
7	17	12	5	7
8	44	39	16	23
9	31	41	25	16
10	12	37	26	11
Totals	240	370	218	152
Means	24.0	37.0	21.8	15.2

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